FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: **R.36138**

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR): **10/018459**

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/DE 00/01626	**20 May 2000**	**19 June 1999**

TITLE OF INVENTION

PIEZOELECTRIC ACTUATOR

APPLICANT(S) FOR DO/EO/US

STOECKLEIN, Wolfgang BOECKING, Friedrich

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☒ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☒ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☒ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☐ Certificate of Mailing by Express Mail
23. ☒ Other items or information:

Transmittal sheets in duplicate w/fees charged to Dep. Acct. 07-2100 - Copy of German Text Appl. w/2 sheets drawings Translation of German Text Appl. w/2 sheets drawings - Letter to the Official Draftsman - Preliminary Amendment Copy of German Text Amended Pages - Translation of German Text Amended Pages - Copy of PCT/RO/101, Copy of PCT/ISA/210 and 220 Copy of PCT/IPEA/401, 409, 416 - Executed Declaration and Assignment (Not Enclosed)

531 Rec'd PCT/ 19 DEC 2001

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR) 10/018459	INTERNATIONAL APPLICATION NO. PCT/DE 00/01626	ATTORNEY'S DOCKET NUMBER R.36138

24. The following fees are submitted:.	CALCULATIONS PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :	
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1040.00	
☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO $890.00	
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO $740.00	
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) $710.00	
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) $100.00	
ENTER APPROPRIATE BASIC FEE AMOUNT =	$890.00
Surcharge of **$130.00** for furnishing the oath or declaration later than ☒ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	$130.00

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	
Total claims	17 - 20 =	0	x $18.00	$0.00
Independent claims	- 3 =	0	x $84.00	$0.00
Multiple Dependent Claims **(check if applicable).**			☐	$0.00

TOTAL OF ABOVE CALCULATIONS =	$1,020.00
☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.	$0.00
SUBTOTAL =	$1,020.00
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +	$0.00
TOTAL NATIONAL FEE =	$1,020.00
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐	$0.00
TOTAL FEES ENCLOSED =	$1,020.00
Amount to be: refunded	$
charged	$

a. ☐ A check in the amount of _____ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. **07-2100** in the amount of **$1,020.00** to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **07-2100** A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Ronald E. Greigg
GREIGG & GREIGG P.L.L.C.
1423 Powhatan Street, Unit One
Alexandria, Virginia 22314

Customer No. 02119

Telephone: (703) 838-5500
Facsimile: (703) 838-5554

SIGNATURE

Ronald E. Greigg
NAME

31,517
REGISTRATION NUMBER

19 December 2001
DATE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of

Wolfgang Stoecklein et al

Based on PCT/DE 00/01626

For: Piezoelectric Actuator

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C.

Sir:

Prior to examination, please amend the above-identified application as follows:

IN THE SPECIFICATION

Page 1, between the title and paragraph [0001], insert:

[0000.2] CROSS-REFERENCE TO RELATED APPLICATIONS

[0000.4] This application is a 35 USC 371 application of PCT/DE 00/01626 filed on May 20, 2000.

[0000.6] BACKGROUND OF THE INVENTION

replace paragraph [0001] with the following amended paragraph:

[0001] Field of the Invention

replace paragraph [0002] with the following amended paragraph:

[0002] The invention relates to a piezoelectric actuator, for instance for actuating a mechanical component such as a valve or the like.

after paragraph [0002], insert the following new paragraph:

[0002.5] Description of the Prior Art

Page 2, replace paragraph [0005] with the following amended paragraph:

[0005] In the conventional way, until now it was possible to reduce such problematic effects only by employing very expensive materials, such as Invar, that have a negative temperature expansion. Another way was to connect a material of high temperature expansion in series with the piezoelectric element, but that reduces the rigidity of the system and hence the useful force.

replace paragraph [0006] with the following amended paragraph:

[0006] SUMMARY OF THE INVENTION

Page 5, replace paragraph [0012] with the following amended paragraph:

[0012] In a first application of the piezoelectric actuator of the invention, the end of the piezoelectric element by which it rests on the pressure plate, and thus exerts a force on the actuating element, can advantageously be disposed on the far side of the piezoelectric actuator in terms of the effective direction. In that case, the useful force of the piezoelectric actuator is a tensile force.

delete paragraph [0014]:

replace paragraph [0015] with the following amended paragraph:

[0015] BRIEF DESCRIPTION OF THE DRAWINGS

Page 6, replace paragraph [0016] with the following amended paragraph:

[0016] Exemplary embodiments of the piezoelectric actuator of the invention with a

narrow design, for instance for positioning a valve, will be explained herein below in conjunction with the drawings, in which:

Page 7, replace paragraph [0025] with the following amended paragraph:

[0025] DESCRIPTION OF THE PREFERRED EMBODIMENTS

Page 8, replace paragraph [0028] with the following amended paragraph:

[0028] The prestressing force F_7 of the spring 7 must be substantially less than the prestressing force F_4 of the spring 4, so that for the maximum useful force F_u, in this case in the form a tensile force, of the piezoelectric actuator 1, the following equation applies:

$$F_u = F_4 - F_7$$

replace paragraph [0030] with the following amended paragraph:

[0030] Figs. 2 and 3 each show an arrangement of barlike piezoelectric elements 2 and compensating elements 3 in a section along the line A-A in Fig. 1. The lead bondings 10, 11 of the piezoelectric elements 2 are done in the Y axis direction in the arrangement of Fig. 2, while lead bondings 12, 13 in Fig. 3 are done in the X direction.

replace paragraph [0031] with the following amended paragraph:

[0031] In Fig. 4, an arrangement with hollow-cylindrical piezoelectric elements 2 and compensating elements 3 can be seen, again in a section along the line A-A

of Fig. 1. In this arrangement, the lead bondings 14 and 15 of the piezoelectric element 2 are mounted on the radial side faces of the piezoelectric element 2.

Page 9, replace paragraph [0032] with the following amended paragraph:

[0032] A second exemplary embodiment of the piezoelectric actuator 1 is shown in Fig. 5, in which the components that function the same are provided with the same reference numerals as for Fig. 1. In the arrangement of Fig. 5 as well, the piezoelectric element 2 is of a suitable piezoceramic; a compensating element 20, however, is also constructed as a piezoelectric element, and in a modification of the example of Fig. 1, these elements 2 and 20 are pressed by the spring 4 via the spring plate 5 against a fixation edge located at the top of the housing 6.

replace paragraph [0033] with the following amended paragraph:

[0033] The piezoelectric element 2 is layered transversely, so that when an electrical voltage is applied, it lengthens, as in the first exemplary embodiment. The piezoelectric layers of the compensating element 20 are conversely longitudinally layered or stacked, so that they shorten in the effective direction when an electrical voltage is applied to the piezoelectric actuator 1.

replace paragraph [0034] with the following amended paragraph:

[0034] The prestressing force of the spring 7, by way of which the lower end of the piezoelectric element 2 rests on the housing, must be substantially less than the prestressing force of the spring 4, so that for the maximum useful force F_u, in this case in the form of a compressive force, of the piezoelectric actuator 1, the following equation applies:

$$F_u = F_7 - F_4$$

Page 11, insert the following new paragraph:

[0038] The foregoing relates to preferred exemplary embodiment of the invention, it being understood that other variants and embodiments thereof are possible within the spirit and scope of the invention, the latter being defined by the appended claims.

Page 12, delete "New Claims 1-7" and insert --We Claim--.

IN THE CLAIMS

Please cancel claims 1-7 and add new claims 8-24.

8. A piezoelectric actuator, comprising

- a piezoelectric element (2) for subjecting an actuating element (9) to a tensile force or compressive force, and a compensating element (3; 20), the piezoelectric element (2) and the compensating element (3; 20) having essentially the same coefficients of temperature expansion, wherein, the piezoelectric element (2) in its effective direction resting with one end against a fixation edge of a housing (6) via a spring (4) and with its other end on another fixation edge of the housing (6) via a pressure plate (8) and a prestressing spring (7), and

- a spring plate (5), which is disposed between the piezoelectric element (2) and the spring (4) and on which the compensating element (3; 20) is additionally disposed, which with its other end abuts the housing (6) firmly and is located essentially parallel to the piezoelectric element (2),

- the piezoelectric element (2) and the compensating element (3; 20) being hollow cylinders, which are disposed about the axis of the actuating element (9).

9. The piezoelectric actuator of claim 8, wherein the piezoelectric element (2) comprises a multilayered structure of transversely disposed ceramic piezoelectric layers, which lengthen in the effective direction when an external electrical voltage is applied, and the compensating element (3) is constructed of ceramic.

10. The piezoelectric actuator of claim 8, wherein the piezoelectric element (2) comprises a multilayered structure of transversely disposed ceramic piezoelectric layers, which lengthen in the effective direction when an external electrical voltage is applied; and that the compensating element (20) comprises longitudinally disposed piezoelectric layers, which shorten in the effective direction when an external electrical voltage is applied.

11. The piezoelectric actuator of claim 8, wherein the piezoelectric element (2) and the compensating element (3; 20) are constructed in bar form, with a substantially round or rectangular cross section.

12. The piezoelectric actuator of claim 9, wherein the piezoelectric element (2) and the compensating element (3; 20) are constructed in bar form, with a substantially round or rectangular cross section.

13. The piezoelectric actuator of claim 10, wherein the piezoelectric element (2) and the compensating element (3; 20) are constructed in bar form, with a substantially round or rectangular cross section.

14. The piezoelectric actuator of claim 8, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the far side of the piezoelectric actuator (1) in terms of the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a tensile force.

15. The piezoelectric actuator of claim 9, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the far side of the piezoelectric actuator (1) in terms of the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a tensile force.

16. The piezoelectric actuator of claim 10, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the far side of the piezoelectric actuator (1) in terms of the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a tensile force.

17. The piezoelectric actuator of claim 11, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the far side of the piezoelectric actuator (1) in terms of the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a tensile force.

18. The piezoelectric actuator of claim 12, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the far side of the piezoelectric actuator (1) in terms of the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a tensile force.

19. The piezoelectric actuator of claim 13, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the far side of the piezoelectric actuator (1) in terms of the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a tensile force.

20. The piezoelectric actuator of claim 8, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the side of the piezoelectric actuator (1) located in the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a compressive force.

21. The piezoelectric actuator of claim 9, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the side of the piezoelectric actuator (1) located in the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a compressive force.

22. The piezoelectric actuator of claim 10, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the side of the piezoelectric actuator (1) located in the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a compressive force.

23. The piezoelectric actuator of claim 8, wherein the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the side of the piezoelectric actuator (1) located in the effective direction, so that the useful force (F_u) of the piezoelectric actuator (1) is a compressive force.

24. The piezoelectric actuator of claim 8, further comprising a heat-conducting paste is disposed between the piezoelectric element (2) and the compensating element (3; 20).

IN THE ABSTRACT

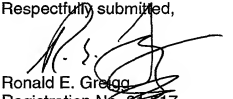
Please substitute the attached Abstract of the Disclosure for the abstract as originally as filed.

REMARKS

The above amendments are being made to place the application in better condition for examination.

Entry of the amendment is respectfully solicited.

Respectfully submitted,



Ronald E. Greigg
Registration No. 31,517
Customer No. 002119
Attorney for Applicants

Greigg & Greigg P.L.L.C.
1423 Powhatan Street, Unit One
Alexandria, VA 22314

Telephone: (703) 838-5500
Facsimile: (703) 838-5554

Page 16, replace the abstract for the following amended abstract of the disclosure:

Abstract

A piezoelectric actuator for actuating a mechanical component includes a piezoelectric element, for subjecting an actuating element to a tensile force or compressive force, and a compensating element, with the piezoelectric element and the compensating element having essentially the same coefficients of temperature expansion. The compensating element is mechanically coupled to the piezoelectric element in such a way that the temperature-caused expansions of the piezoelectric element and of the compensating element cancel one another out in the effective direction in such a way that the actuating element remains in its position.

VERSION WITH MARKINGS TO SHOW CHANGES MADE

Page 1, paragraphs [0000.2] through [0002.5]:

[0000.2] CROSS-REFERENCE TO RELATED APPLICATIONS

[0000.4] This application is a 35 USC 371 application of PCT/DE 00/01626 filed on May 20, 2000.

[0000.6] BACKGROUND OF THE INVENTION

[0001] [Prior Art] Field of the Invention

[0002] The invention relates to a piezoelectric actuator, for instance for actuating a mechanical component such as a valve or the like[, in accordance with the generic characteristics of the preamble to the main claim].

[0002.5] Description of the Prior Art

Page 2, paragraphs [0005] and [0006]:

[0005] In the conventional way, until now it was possible to reduce such problematic effects only by employing very expensive materials, such as Invar, that have a negative temperature expansion. Another way was to connect a material of high temperature expansion in series with the piezoelectric element, but that reduces the rigidity of the system and hence the [ak] useful force.

[0006] [Advantage of the Invention] SUMMARY OF THE INVENTION

Page 5, paragraphs [0012] through [0015]:

[0012] In a first application of the piezoelectric actuator of the invention, the end of the piezoelectric element by which it rests on the pressure plate, and thus

exerts a force on the actuating element, can advantageously be disposed on the far side of the piezoelectric actuator in terms of the effective direction. In that case, the useful force of the piezoelectric actuator is a tensile force.

[0014] [These and other characteristics of preferred refinements of the invention will become apparent from the claims and the description and the drawings; the individual characteristics, each alone or a plurality of them in the form of subsidiary combinations, can be realized in the embodiment of the invention and in other fields and can represent both advantageous and intrinsically patentable embodiments for which patent protection is here claimed.]

[0015] [Drawing] BRIEF DESCRIPTION OF THE DRAWINGS

Page 6, paragraph [0016]:

[0016] Exemplary embodiments of the piezoelectric actuator of the invention with a narrow design, for instance for positioning a valve, will be explained herein below in conjunction with the [drawing. Shown are] drawings, in which:

Page 7, paragraph [0025]:

[0025] [Description of the Exemplary Embodiments] DESCRIPTION OF THE PREFERRED EMBODIMENTS

Page 8, paragraphs [0028] through [0031]:

[0028] The prestressing force F_7 of the spring 7 must be substantially less

than the prestressing force F_4 of the spring 4, so that for the maximum useful force [F_{useful},] F_u, in this case in the form a tensile force, of the piezoelectric actuator 1, the following equation applies:

[F_{useful}] $F_u = F_4 - F7$

[0030] Figs. 2 and 3 each show an arrangement of barlike piezoelectric elements 2 and compensating elements 3 in a section along the line A-A in Fig. 1. The lead bondings 10, 11 of the piezoelectric elements 2 are done in the axis Y direction in the arrangement of Fig. 2, while lead bondings 12, 13 in Fig. 3 are done in the X direction.

[0031] In Fig. 4, an arrangement with hollow-cylindrical piezoelectric elements 2 and compensating elements 3 can be seen, again in a section along the line A-A of Fig. 1. In this arrangement, the lead bondings 14 and 15 of the piezoelectric [elements] element 2 are mounted on the radial side faces of the piezoelectric element 2.

Page 9, paragraphs [0032] through [0034]:

[0032] A second exemplary embodiment of the piezoelectric actuator 1 is shown in Fig. 5, in which the components that function the same are provided with the same reference numerals as for Fig. 1. In the arrangement of Fig. 5 as well, the piezoelectric element 2 is of a suitable piezoceramic; a compensating element 20, however, is also constructed [like] as a piezoelectric element, and in a modification

of the example of Fig. 1, these elements 2 and 20 are pressed by the spring 4 via the spring plate 5 against a fixation edge located at the top of the housing 6.

[0033] The piezoelectric element 2 is layered transversely, so that when an electrical voltage is applied, it lengthens, as in the first exemplary embodiment. The piezoelectric layers of the compensating element 20 are conversely longitudinally layered or stacked, so that they shorten in the effective direction when an electrical voltage is applied [of] to the piezoelectric actuator 1.

[0034] The prestressing force of the spring 7, by way of which the lower end of the piezoelectric element 2 rests on the housing, must be substantially less than the prestressing force of the spring 4, so that for the maximum useful [F_{useful}] force E_u, in this case in the form of a compressive force, of the piezoelectric actuator 1, the following equation applies:

$$[F_{useful}]\ E_u = F_7 - F_4$$

Page 11, paragraph [0038]:

[0038] The foregoing relates to preferred exemplary embodiment of the invention, it being understood that other variants and embodiments thereof are possible within the spirit and scope of the invention, the latter being defined by the appended claims.

Page 16, abstract:

Abstract of the Disclosure

A piezoelectric actuator[, for instance] for actuating a mechanical component[, is proposed in which] includes a piezoelectric element [(2)], for subjecting an actuating element [(9)] to a tensile force or compressive force, and a compensating element, with [(3; 20) are present;] the piezoelectric element [(2)] and the compensating element [(3; 20) have] having essentially the same coefficients of temperature expansion. The compensating element [(3; 20)] is mechanically coupled to the piezoelectric element [(2)] in such a way that the temperature-caused expansions of the piezoelectric element [(2)] and of the compensating element [(3; 20)] cancel one another out in the effective direction in such a way that the actuating element [(9)] remains in its position.

[(Fig. 1)]

PIEZOELECTRIC ACTUATOR

[0001] Prior Art

[0002] The invention relates to a piezoelectric actuator, for instance for actuating a mechanical component such as a valve or the like, in accordance with the generic characteristics of the preamble to the main claim.

[0003] It is widely known that by utilizing the so-called piezoelectric effect, a piezoelectric element can be constructed from a material with a suitable crystalline structure. When an external electrical voltage is applied, a mechanical reaction of the piezoelectric element takes place, which depending on the crystalline structure and the regions where the electrical voltage is applied causes a compression or tension in a predeterminable direction.

[0004] The aforementioned piezoelectric actuators are often used in the positioning of valves. Among other factors, it must be considered here that their stroke capacity for actuating a valve tappet, for instance, is relative slight. On the other hand, the different thermal expansion of the ceramic comprising the piezoelectric element as opposed to the housing causes problems; the piezoelectric element has only very slight temperature expansion, and the housing, which as a rule is of metal, has a positive temperature expansion, which

can cause a drift in the position of the valve tappet without any triggering of the piezoelectric element.

[0005] In the conventional way, until now it was possible to reduce such problematic effects only by employing very expensive materials, such as Invar, that have a negative temperature expansion. Another way was to connect a material of high temperature expansion in series with the piezoelectric element, but that reduces the rigidity of the system and hence the ak force.

[0006] Advantages of the Invention

[0007] The piezoelectric actuator described at the outset, which can be used for instance to actuate a mechanical component, advantageously has a piezoelectric element, parallel to which, according to the invention, a compensating element is disposed. It is especially advantageous that the piezoelectric element and the compensating element have essentially the same coefficients of temperature expansion, so that given a suitable mechanical mounting of the two elements, the temperature-caused expansions in the piezoelectric element and the compensating element cancel one another out in the effective direction in such a way that an actuating element solidly connected to a pressure plate of the piezoelectric element remains in its position. It is thus possible in a simple way to use a metal housing, for instance of steel, for the piezoelectric actuator as before and to brace the

piezoelectric element in the housing in such a way that the compensating element is always solidly connected to the piezoelectric element for the sake of temperature compensation.

[0008] In an advantageous embodiment, the piezoelectric element in its effective direction rests with one end against a fixation edge of a housing via a spring and with its other end on another fixation edge of the housing via a pressure plate and a prestressing spring. A spring plate is also present, which is disposed between the piezoelectric element and the spring. According to the invention, the compensating element is additionally disposed on this spring plate and with its other end abuts the housing firmly and moreover is parallel to the piezoelectric element.

[0009] In a first refined embodiment, the piezoelectric element comprises a multilayered structure of transversely disposed ceramic piezoelectric layers, which lengthen in the effective direction when an external electrical voltage is suitably applied. The compensating element is likewise constructed of ceramic, with the same coefficients of temperature expansion as the layers of piezoceramic, but this ceramic has no piezoelectric effect. A possible differential expansion between the housing of the piezoelectric actuator and the piezoelectric element that would cause a deflection of the actuating element is thus compensated for via the spring

that is located between the spring plate and the fixation edge of the housing.

[0010] In a second embodiment, the piezoelectric element likewise comprises a multilayered structure of transversely disposed ceramic piezoelectric layers, which lengthen in the effective direction when an external electrical voltage is applied. The compensating element here is constructed of longitudinally disposed piezoelectric layers, which shorten in the effective direction when an external electrical voltage is applied. Once again, as mentioned above, a possible differential expansion between the piezoelectric actuator housing and the piezoelectric element can be compensated for by means of the same temperature coefficient for the piezoelectric element and the compensating element and by means of the compensation via the aforementioned spring. However, in addition, this embodiment of the invention also makes it possible to lengthen the stroke of the piezoelectric actuator, so that other additional provisions such as a hydraulic coupling can be dispensed with. Because of the lengthened stroke, an otherwise possibly necessary stroke boost can also be dispensed with.

[0011] In advantageous refinements of the invention, the piezoelectric element and the compensating element can be constructed in bar form, with a round or rectangular cross section. It is also possible here for the piezoelectric element and the compensating element to comprise hollow

cylinders, which are disposed about the axis of the actuating element, to make an overall cylindrical design of the piezoelectric actuator easier.

[0012] In a first application of the piezoelectric actuator of the invention, the end of piezoelectric element by which it rests on the pressure plate, and thus exerts a force on the actuating element, can advantageously be disposed on the far side of the piezoelectric actuator in terms of the effective direction. In that case, the useful force of the piezoelectric actuator is a tensile force.

[0013] In a second advantageous application, the end of piezoelectric element by which it rests on the pressure plate, is disposed on the side of the piezoelectric actuator located in the effective direction. In this second case, the useful force of the piezoelectric actuator is a compressive force.

[0014] These and other characteristics of preferred refinements of the invention will become apparent from the claims and the description and the drawings; the individual characteristics, each alone or a plurality of them in the form of subsidiary combinations, can be realized in the embodiment of the invention and in other fields and can represent both advantageous and intrinsically patentable embodiments for which patent protection is here claimed.

[0015] Drawing

[0016] Exemplary embodiments of the piezoelectric actuator of the invention with a narrow design, for instance for positioning a valve, will be explained in conjunction with the drawing. Shown are:

[0017] Fig. 1, a section through a piezoelectric actuator, acting with a tensile force, with a compensating element of ceramic;

[0018] Fig. 2, a section taken along the line A-A of Fig. 1, with a barlike design of the piezoelectric element of Fig. 1 and showing a first possibility for lead bonding;

[0019] Fig. 3, a section corresponding Fig. 2, with a second possibility for lead bonding;

[0020] Fig. 4, a section taken along the line A-A of Fig. 1, with a hollow-cylindrical design of the piezoelectric element of Fig. 1;

[0021] Fig. 5, a section through a piezoelectric actuator, acting with a compressive force, with a compensating element of piezoceramic layers;

[0022] Fig. 6, a section taken along the line A-A of Fig. 5 with a barlike design of the piezoelectric elements of Fig. 5 and showing a first possibility for lead bonding;

[0023] Fig. 7, a section corresponding to Fig. 6, showing a second possibility for lead bonding; and

[0024] Fig. 8, a section taken along the line A-A of Fig. 5, with a hollow-cylindrical design of the piezoelectric elements of Fig. 5.

[0025] Description of the Exemplary Embodiments

[0026] In Fig. 1, a piezoelectric actuator 1 is shown, which has a piezoelectric element 2 that in a manner known per se is constructed of piezoelectric sheets of a quartz material of a suitable crystalline structure, so that by utilizing the so-called piezoelectric effect, when an external electrical voltage is applied to electrodes, not shown in this drawing, a mechanical reaction of the piezoelectric actuator 1 ensues.

[0027] In the piezoelectric actuator 1 of Fig. 1, the piezoelectric element 2 is of ceramic, and a compensating element 3, also of ceramic but without a piezoelectric effect, is pressed by a spring 4 via a spring plate 5 against a fixation edge of the housing 6. The elements 2 and 3 have the same coefficients of temperature expansion. The piezoelectric element 2 is prestressed from above by the prestressing spring 7 and a pressure plate 8, and the piezoelectric element 2 is constructed with transversely stacked layers in such a way that it lengthens when an electrical voltage is applied. The pressure plate 8 is solidly connected to a tie rod 9, which

represents the actuating element, for instance for a valve tappet.

[0028] The prestressing force F_7 of the spring 7 must be substantially less than the prestressing force F_4 of the spring 4, so that for the maximum useful force F_{useful}, in this case in the form a tensile force, of the piezoelectric actuator 1, the following equation applies:

$$F_{useful} = F_4 - F_7$$

[0029] The stiffnesses of the springs 4 and 7 should be as slight as possible. Since the temperature expansion of the piezoelectric element 2 is the same as that of the compensating element 3, any possible differential expansion between the housing 6 and piezoelectric element 2 is compensated for via the spring 4.

[0030] Figs. 2 and 3 each show an arrangement of barlike piezoelectric elements 2 and compensating elements 3 in a section along the line A-A in Fig. 1. The lead bondings 10, 11 of the piezoelectric elements 2 are done in the Y direction in the arrangement of Fig. 2, while lead bondings 12, 13 in Fig. 3 are done in the X direction.

[0031] In Fig. 4, an arrangement with hollow-cylindrical piezoelectric elements 2 and compensating elements 3 can be seen, again in a section along the line A-A of Fig. 1. In

this arrangement, the lead bondings 14 and 15 of the piezoelectric elements 2 are mounted on the radial side faces of the piezoelectric element 2.

[0032] A second exemplary embodiment of the piezoelectric actuator 1 is shown in Fig. 5, in which the components that function the same are provided with the same reference numerals as for Fig. 1. In the arrangement of Fig. 5 as well, the piezoelectric element 2 is of a suitable piezoceramic; a compensating element 20, however, is also constructed like a piezoelectric element, and in a modification of the example of Fig. 1, these elements 2 and 20 are pressed by the spring 4 via the spring plate 5 against a fixation edge located at the top of the housing 6.

[0033] The piezoelectric element 2 is layered transversely, so that when an electrical voltage is applied, it lengthens, as in the first exemplary embodiment. The piezoelectric layers of the compensating element 20 are conversely longitudinally layered or stacked, so that they shorten in the effective direction when an electrical voltage is applied of the piezoelectric actuator 1.

[0034] The prestressing force of the spring 7, by way of which the lower end of the piezoelectric element 2 rests on the housing, must be substantially less than the prestressing force of the spring 4, so that for the maximum useful F_{useful}, in this case in the form of a compressive force, of the

piezoelectric actuator 1, the following equation applies:

$$F_{useful} = F_7 - F_4$$

[0035] Once again, the stiffnesses of the springs 4 and 7 should be as slight as possible. When an electrical voltage is applied to the two elements 2 and 20, the sum of the two individual strokes of the two elements 2 and 20 is the resultant useful stroke. Since here again the temperature expansion of the two elements 2 and 20 is the same, any possible differential expansion between the housing 6 and the piezoelectric element 2 is once again compensated for via the spring 4.

[0036] In Fig. 6 and Fig. 7, an arrangement with a barlike piezoelectric element 2 and likewise barlike compensating elements 20 can be seen in a section taken along the line A-A in Fig. 5. In Fig. 6, the lead bondings of the piezoelectric element 2 are made in the X direction and those of the compensating element 20 are made in the Y direction, while in the arrangement of Fig. 7, they are made in the Y direction for the piezoelectric element 2 and in the X direction for the compensating elements 20.

[0037] In Fig. 8, an arrangement with hollow-cylindrical piezoelectric elements 2 and compensating elements 20 can be seen, again in a section taken along the line A-A of Fig. 5. The lead bondings 14 and 15 of the piezoelectric element 2 and

the compensating element 20 in this arrangement are mounted on the radial side faces.

New Claims 1-7

1. A piezoelectric actuator, having

- a piezoelectric element (2) for subjecting an actuating element (9) to a tensile force or compressive force, and having a compensating element (3; 20), the piezoelectric element (2) and the compensating element (3; 20) having essentially the same coefficients of temperature expansion, wherein

- the piezoelectric element (2) in its effective direction rests with one end against a fixation edge of a housing (6) via a spring (4) and with its other end on another fixation edge of the housing (6) via a pressure plate (8) and a prestressing spring (7),

- having a spring plate (5), which is disposed between the piezoelectric element (2) and the spring (4) and on which the compensating element (3; 20) is additionally disposed, which with its other end abuts the housing (6) firmly and is located essentially parallel to the piezoelectric element (2), and wherein

- the piezoelectric element (2) and the compensating

element (3; 20) comprise hollow cylinders, which are disposed about the axis of the actuating element (9).

2. The piezoelectric actuator of claim 1, characterized in that the piezoelectric element (2) comprises a multilayered structure of transversely disposed ceramic piezoelectric layers, which lengthen in the effective direction when an external electrical voltage is applied, and the compensating element (3) is constructed of ceramic.

3. The piezoelectric actuator of claim 1, characterized in that the piezoelectric element (2) comprises a multilayered structure of transversely disposed ceramic piezoelectric layers, which lengthen in the effective direction when an external electrical voltage is applied; and that the compensating element (20) comprises longitudinally disposed piezoelectric layers, which shorten in the effective direction when an external electrical voltage is applied.

4. The piezoelectric actuator of one of the foregoing claims, characterized in that the piezoelectric element (2) and the compensating element (3; 20) are constructed in bar form, with a round or rectangular cross section.

5. The piezoelectric actuator of one of the foregoing claims, characterized in that the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the far side of the piezoelectric actuator (2) in terms of

the effective direction, so that the useful force (F_{useful}) of the piezoelectric actuator (1) is a tensile force.

6. The piezoelectric actuator of one of claims 1-4, characterized in that the end of piezoelectric element (2), by which it rests on the pressure plate (8), is disposed on the side of the piezoelectric actuator (2) located in the effective direction, so that the useful force (F_{useful}) of the piezoelectric actuator (1) is a compressive force.

7. The piezoelectric actuator of one of the foregoing claims, characterized in that a heat-conducting paste is disposed between the piezoelectric element (2) and the compensating element (3; 20).

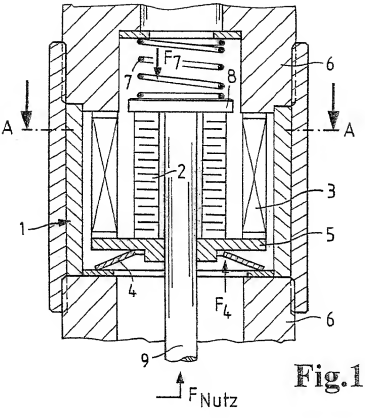


Fig.1

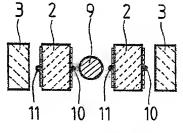


Fig.2

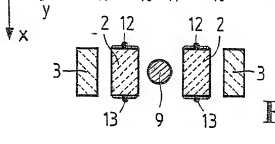


Fig. 3

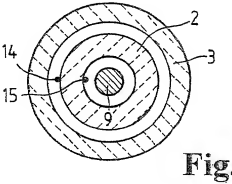


Fig.4

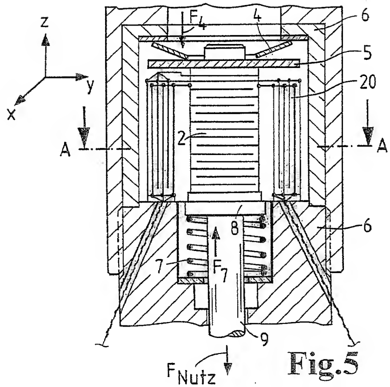


Fig.5

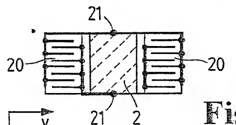


Fig.6

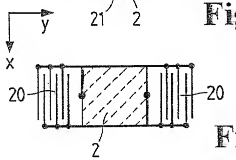


Fig.7

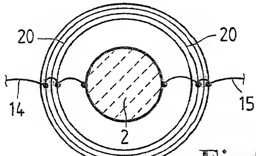


Fig.8

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of

Wolfgang Stoecklein et al

Based on PCT/DE 00/01626

For: Piezoelectric Actuator

LETTER TO THE OFFICIAL DRAFTSMAN

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Please find attached two sheets of drawings with corrections as marked in red.

Respectfully submitted,

Ronald E. Greigg
Registration No. 31,517
Attorney for Applicants
Customer No. 002119

Greigg & Greigg P.L.L.C.
1423 Powhatan Street
Unit One
Alexandria, Virginia 22314

Telephone: 703-838-5500
Facsimile: 703-838-5554

Date: December 19, 2001

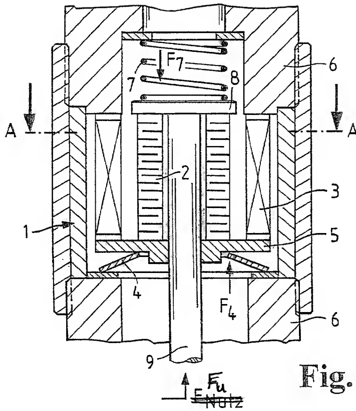


Fig.1

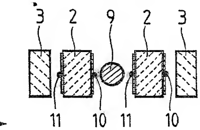


Fig.2

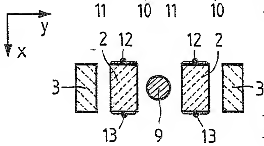


Fig. 3

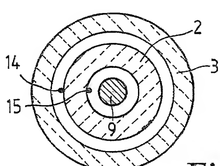


Fig.4

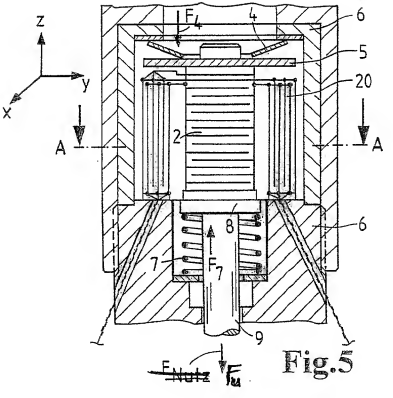


Fig.5

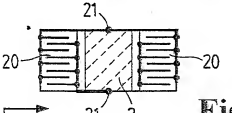


Fig.6

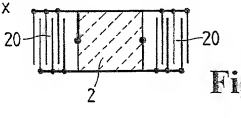


Fig.7

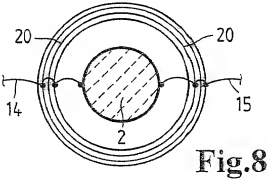


Fig.8

Docket No.
R. 36138

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

PIEZOELECTRIC ACTUATOR

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on **20 May 2000** as United States Application No. or PCT International Application Number **PCT/DE 00/01626**

and was amended on _____
(if applicable)

☐ I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

☐ I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)			Priority Claimed
1 99 28 179.3	**Germany**	**19 June 1999**	☒
(Number)	(Country)	(Day/Month/Year Filed)	
			☐
(Number)	(Country)	(Day/Month/Year Filed)	
			☐
(Number)	(Country)	(Day/Month/Year Filed)	

I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional application(s) listed below:

(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

Ronald E. Greigg, Registration No. 31,517

Send Correspondence to: **Ronald E. Greigg**
Greigg & Greigg, P.L.L.C.
1423 Powhatan Street, Unit One
Alexandria, VA 22314

Direct Telephone Calls to: *(name and telephone number)*
Ronald E. Greigg- (703) 838-5500/Telephone - (703) 838-5554/Facsimile

1-D

Full name of sole or first inventor
Wolfgang STOECKLEIN

Sole or first inventor's signature — Date 18.2.02

Residence
70197 Stuttgart, Germany

Citizenship
Deutsch DEX

Post Office Address
~~Rotebuchstr. 118~~ Ludwigstr. 346

70197 Stuttgart, Germany 70176 Stuttgart

2-D

Full name of second inventor, if any
Friedrich BOECKING

Second inventor's signature — Date 18.2.02

Residence
70499 Stuttgart, Germany

Citizenship
Deutsch DEX

Post Office Address
~~Mainzer Str. 27~~ Uhlbacherstr. 34

70499 Stuttgart, Germany